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PROVISIONAL SPECIFICATION

Invention Title: **Optical data carrier system**

The invention is described in the following statement:

Optical data carrier system

Field of the Invention

The present invention relates broadly to optical data carriers, to a method of optimising a sampling function for the holographic storing of data in an optical data carrier, and to a method of storing data in a disk-shaped optical data carrier.

Background of the Invention

Recent progress in communication transmission rates has not been matched with a storage capacity growth. For example 7 years ago the standard system communication speed was 1.6Gb/s and now it is 320Gb/s (10Gb x 32 channels), which gives an improvement factor of 200. In comparison the corresponding standard media capacity growth from CD (0.8GB) to DVD (10GB) has not been a very convincing move (a factor 12.5 improvement).

On the other hand the theoretical storage limit of standard plane surface pixel-based approach (10Gb per standard CD-size disk) has almost been reached. It is this "x32" (or more) factor, which is missing in the current optical storage technology. The question is how to get it?

Holographic data storage, where information is stored in form of volumetric structures written inside an optical recording medium promises high bit density, arising from the three-dimensional volumetric nature of the storage process.

In at least preferred embodiments, the present invention seeks to provide a novel optical data carrier system which is suitable for taking advantage of the 3-dimensional volumetric nature of an optical data storage process.

Summary of the Invention

In accordance with a first aspect of the present invention, there is provided an optical data carrier having a data reading face and comprising a plurality of grating structures in each of which a series of m-level coded elements, $m \geq 2$, is stored, the grating structures being optically accessible from the reading face for reading of the series of coded elements.

Preferably, a maximum in the refractive index variation defining the grating structures in the optical data carrier is less than directly proportional to the number of coded data elements in each grating structure.

The optical data carrier may be disk-shaped.

The grating structures may comprise one- or multi-dimensional grating structures.

In one embodiment, the optical data carrier comprises a rolled-up material strip in which the plurality of grating structures are formed. Preferably, the optical data carrier comprises means for maintaining the material strip in a rolled-up state. The means for maintaining may comprise a curable material. The means for maintaining may comprise a mechanical structure.

In accordance with a second aspect of the present invention there is provided a method of optimising a sampling function for the holographic storing of a series of m-level coded elements in an optical data carrier, $m \geq 2$, the method comprising the step of:

a) forming the sampling function as a direct sum of N partial grating sampling functions, each partial grating sampling function having phases and amplitudes, represented by φ_n, d_n, respectively;

wherein each d_n has m possible values.

Preferably, the method further comprises:

b) conducting an optimisation process to determine a set of phases φ_n for which a required maximum refractive index variation in the optical data carrier is less than directly proportional to the number of coded data elements in the series.

In one embodiment, step a) comprises:

a1) forming the sampling function as a direct sum of L groups of N partial grating sampling functions, each of LxN partial grating sampling functions having phases and amplitudes, represented by matrices φ_{nl}, d_{nl}, respectively;

and step b) comprises:

b1) separating the matrix φ_{nl} into sets of N phases for each group of N partial grating sampling functions in a given group, and one set of L phases between the L groups;

b2) determining the sets of phases for each group of N partial grating sampling functions from a database having stored therein possible combinations of N coded data elements and associated sets of phases; and

b3) conducting an optimisation process to determine the set of L phases for the L groups for which a required maximum refractive index variation in the optical data carrier is less than directly proportional to the number of coded data elements in the series.

In a preferred embodiment, step b3) comprises conducting the optimisation process to determine the set of L phases for the L groups for which a functional of the sampling function is minimised.

The functional may comprise a mean-square deviation or a maximum amplitude deviation.

Preferably, step b3) comprises applying a functional analysis to determine the set of L phases for the L groups for which the functional of the sampling function is minimised. The functional analysis may comprise a steepest descent (gradient) method.

Step b3) preferably comprises approximating the functional of the sampling function utilising an aperiodic autocorrelation function. Step b3) advantageously further comprises deriving a gradient of the functional of the sampling function from a derivative of the aperiodic autocorrelation function.

The partial grating sampling functions may comprise one- or multi-dimensional functions.

The applicant has recognised that the problem of Fourier space optical storage encoding is conceptually similar to a multi-channel fiber Bragg grating (FBG) optimization problem. An efficient theoretical tool for designing the multi-channel FBGs is the so-called dephasing approach. A characteristic property of the FBGs obtained using the dephasing approach is that the reflection spectrum consists of a uniform sequence of identical channels.

The applicant has also recognised that in the context of high capacity optical storage devices, such multi-channel FBG optimisation has at least the following drawbacks: Firstly, the multi-channel FBGs with identical reflection channels are capable of storing only one type of data elements (e.g., "1") whereas storing codewords in an optical data carrier requires the possibility of using at least two types of data elements, e.g. bits "1" and "0". In addition, the prior art optimization methods work reasonably *fast* only for a fairly small number of channels (e.g. <50), whereas the encoding optimization problems may involve a lot longer bit sequences (e.g. up to 100,000,000 or more).

At least a preferred embodiment of the second aspect of the present invention provides a novel method of optimising a sampling function for the holographic storing of data which addresses those above mentioned drawbacks.

In accordance with a third aspect of the present invention there is provided a method of storing data in an optical data carrier, the method comprising the steps of storing the data into a material strip, and arranging the material strip to form the optical data carrier and in a manner such that the data is optically accessible from a reading face of the optical data carrier for reading the stored data.

In one embodiment, arranging the material strip comprises spooling the material strip into a disk-shaped optical data carrier.

The material strip may comprise a photosensitive material strip, and the step of storing the data comprises photo-inducing refractive index changes in the photosensitive material strip to form grating structures for holographically storing the data.

In accordance with a fourth aspect of the present invention there is provided an optical data carrier comprising a material strip arranged in a manner such that data stored in the material strip is optically accessible from a reading face of the optical data carrier for reading the data.

In one embodiment, the optical data carrier is disk-shaped and comprises the material strip spooled into a disk shape.

The material strip may comprise a plurality of grating structures containing the optical data, and wherein each grating structure is optically accessible from the reading face.

The optical data carrier may further comprise means for releasably maintaining the material strip in the disk shape.

Brief description of the drawings

Preferred embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings.

Figure 1 illustrates schematically the difference between a conventional "flat" storage of CD/DVD-type disk and a holographic disk embodying the present invention.

Figure 2 shows a sample two-level coding sequence (in Fourier space) (a), (b) and the corresponding amplitude grating design both without clipping (c) and with clipping (d).

Figure 3 is a schematic drawings illustrating an optical data carrier writing system and method embodying the present invention.

Figure 4 is a schematic drawing illustrating an optical data carrier embodying the present invention.

Detailed description of the embodiments

Figure 1 illustrates schematically the difference between conventional "flat" storage of CD/DVD-type disk 10 and an example volumetric holographic disk 13 storage embodying the present invention. In a CD/DVD-type disk 10 each pixel, e.g. 12, on a 2D plane 14 can either reflect the scanning beam (bit "1") or not (bit "0"). In the disc 13, the 2D pixel structure is retained, but instead of a single "flat" reflector a volumetric multi-channel grating e.g. 16 with total reflection at certain set of angles (numeral 18, "1"s) and total transmission at other set of angles (numeral 20, "0"s) is used. Alternatively, instead of using different measurement angles, a set of measurements at different wavelengths can be performed.

It will be appreciated by a person skilled in the art that each of the gratings e.g. 16 is directly optically accessible from a reading face 17 of the disc 13, i.e. the gratings, e.g. 16 are aligned along the reading face, with no grating shadowing the other for a chosen optical reading beams 19.

It can be shown that for the standard semiconductor red laser wavelength (650 nm) such a multi-channel grating may have more than 1000 distinct channels see below. Thus each pixel e.g. 12, 14 of the CD/DVD-type disk 11 can be replaced by example 1000 "pixels" e.g. 16 of the holographic disk 13.

Estimates related to the simplest (quasi 1D) holographic solutions:

The grating length may be estimated from a simple formula: $\Delta z \approx 1/\Delta\delta$. In this expression, the grating length Δz is measured in [cm] and the spectral width $\Delta\delta$ is measured in special normalised units [1/cm], which are related to real life spectral width (e.g. in [nm]) as $\Delta\delta = 20\pi n_0 \Delta\delta_{nm} / \lambda^2$, where λ is the grating central wavelength [in microns]. For example for $\lambda \approx 0.65$ micron and $\Delta z = 1$ mm we get $\Delta\delta_{nm} = 0.023$ nm.

The maximum number of channels for a given λ and Δz is given as $N \approx 0.2\lambda / \Delta\delta_{m}(\Delta z)$. For example for $\lambda \approx 0.65$ micron and $\Delta z = 1$ mm we get $N \approx 6000$.

An estimate for the maximum required Δn_{max} change is also possible. In the first approximation one can express the grating amplitude parameter as $q(z) = -2\int_{-\infty}^{\infty}\sqrt{R(\delta)}\exp(-2i\delta z)d\delta$, where R is reflectivity. Taking $\sqrt{R(\delta)} = \sqrt{R}\exp(-\delta^2 / \Delta\delta^2)$ one may further estimate $q(z) = -2\sqrt{\pi}\Delta\delta\sqrt{R}\exp(-z^2\Delta\delta^2)$ or $|q_{max}| = 2\sqrt{\pi R}\Delta\delta = 2\sqrt{\pi R} / \Delta z$. This gives an expression for $\Delta n_{max} = 2\lambda_0 n_0\sqrt{R/\pi} / \Delta z$. For $R = 0.5$, $\lambda_0 = 0.65$ microns, $n_0 = 1.5$, and $\Delta z = 0.1$ cm we get $\Delta n_{max} \approx 10^{-3}$, which is a realistic requirement for UV interferometric grating writing techniques.

However the obtained estimate is for a single channel grating only. If a N-channel grating is to be written, then an extra factor of $\sqrt{N}$ appears (this already takes into account dephasing optimisation without which one would have N factor instead). For $N = 1000$, this gives an extra factor of about 30 or $\Delta n_{max} \approx 3\cdot 10^{-2}$. This corresponds to state-of-the-art materials. Photosensitive materials capable to produce the refractive index change of $\Delta n_{max} \approx 10^{-1}$ or more (together with other general requirements like low shrinkage, good mechanical properties, etc) may become available in the future.

The example embodiments described provide a novel Fourier encoding approach for applications in high capacity optical data storage and other fields, which can be implemented with readily available materials.

In the example embodiment, the one-level (identical signals) dephasing approach used for multi-channel fiber Bragg grating optimisation is modified to accommodate coded signals. In addition, the preferred embodiment achieves the significant speed improvement through two other key modifications:

Instead of using time-consuming fully numerical algorithms, the problem is simplified by calculating the so-called *reduced mean deviation function* and its derivatives with respect to phase values analytically, drastically reducing the amount of numerical calculations.

A block (convolution) optimization approach is applied, where the total number of encoded information elements is factorized and optimized in distinct steps. It has been found that, by small (few percent) sacrifice of the optimization quality, one gains substantially in the speed of numerical calculations.

As a result, the example embodiment provides a fast and efficient m-level Fourier encoding optimization approach. Below it will be described for $m=2$ level coded (i.e. binary) elements, but it will be appreciated by a person skilled in the art that the present invention can be expanded or generalised to higher $(m > 2)$-level coded elements without departing from the spirit or scope of the present invention.

Similar to a single-channel FBG, one bit of information can be written into e.g. a holographic data disk by irradiating the photosensitive material of the disk with laser light, the intensity profile of which is proportional to the grating design $q(z)=\kappa(z)\exp[i(K_0 z+\theta(z))]$, where z is the depth direction of the disk, $\kappa(z)$ is the grating amplitude and $\theta(z)$ is the grating phase, K_0 is the grating wave number. The grating amplitude $\kappa(z)$ is measured in cm^{-1} and is related to the disk effective refractive index modulation Δn as $\kappa(z)=\pi\Delta n(z)/(2\Lambda_0 n_0)$, where Λ_0 is the period and n_0 is the average refractive index. Recording $L\times N$ bits (N is the number of bits in a codeword, L is the number of codewords) into the disk can be accomplished via periodical modulation (i.e. sampling) of the one-bit design: $q(z)=\kappa(z)\exp[i(K_0 z+\theta)]S(z)$, where $S(z)$ is a periodical sampling function (complex) with the period $T=2\pi/\Delta k$ defined by the desirable inter-channel spacing Δk.

The first step of the example embodiment encoding algorithm deals with the specific representation of $S(z)$. The sampling function is presented as the direct sum of $L\times N$ partial gratings, equally spaced in the frequency domain, and having relative phases φ_{nl} and amplitudes $d_{nl}=\{d_0, d_1\}$, $n=1,\ldots,N$, $l=1,\ldots,L$:

$$S(z)=\sum_{l=1}^{L}\sum_{n=1}^{N} d_{nl}\exp[i(2n+2N(l-1)-1-NL)\Delta kz/2+\phi_{nl})].$$

The second step is to transform two-dimensional matrixes d_{nl}, φ_{nl} into a one-dimensional complex sequence m_p, $p=1,2,\ldots,NL$, where $m_{n+N(l-1)}=d_{nl}\exp(i\varphi_{nl})$.

Complete optimization of the sampling function would comprise numerical search for all $L \times N$ phases φ_{nl} based on modified prior art techniques. For a high number of the recorded bits *(e.g.* $L \times N > 100$) this approach may not be feasible due to excessive computational time.

Therefore, in the example embodiment the number of variables is decreased by presenting the relative phases of the partial gratings in the form $\varphi_{nl} = \varphi_{nl}^{N} + \varphi_{l}^{L}$, where φ_{nl}^{N} for a fixed l are the N phases that optimize the l-th codeword. The phases φ_{nl}^{N} are taken, i.e. not calculated, from a database of preliminary results.

Optimization of all possible codewords (i.e. all possible combinations of $\{d_0, d_1\}$ levels), for example using prior art methods, might be accomplished as a preliminary step for creation of the database.

The rest of the phases, a set of L unknown variables φ_{l}^{L}, represents the relative phases between the codewords. Below is the detailed description of how to obtain these L phases in an efficient way in the example embodiment.

An algorithm to obtain L phases φ_{l}^{L} has been developed, which comprises two distinct steps: minimization of the mean-square deviation of the sampling function followed by an iterative procedure of further peak amplitude degradation.

It has been shown that the peak amplitude of the sampling function is not high when its mean-square deviation is small. The mean-square deviation $\Delta(\varphi)$ of the sampling function can be approximated accurately by an expression measuring the total energy of the aperiodic autocorrelation function C_k of sequence m_p:

$$\Delta(\varphi) \cong \frac{1}{\sqrt{2}NL}\left(\sum_{k=1}^{NL-1}|C_k|^2\right)^{1/2},$$

where

$$C_k = \sum_{p=1}^{NL-k} m_{p+k} m_p^{*}, \quad k = 1,2,\ldots,NL-1,$$

and "*" denotes complex conjugate. The main advantage of this approximation is a high efficiency of the numerical calculations when searching for the optimal set of phases. It is based

on the possibility to derive an analytical expression for the gradient (direction towards the optimum) of the objective function,

$$\frac{\partial\Delta(\varphi)}{\partial\varphi_j^L} = \frac{\Delta(\varphi)}{\sum_{k=1}^{NL-1}|C_k|^2}\mathrm{Re}\left\{\sum_{k=1}^{NL-1} C_k^* \frac{\partial C_k}{\partial\varphi_j^L}\right\}, \tag{1}$$

where Re stands for the real part. To calculate the above expression analytically we present the derivative of the autocorrelation function in the following form,

$$\frac{\partial C_k}{\partial\varphi_j^L} = \sum_{p=k+1}^{NL} \frac{\partial m_p}{\partial\varphi_j^L} m_{p-k}^* + \sum_{p=1}^{NL-k} m_{p+k} \frac{\partial m_p^*}{\partial\varphi_j^L}\ . \tag{2}$$

We also present the autocorrelation index k and the sequence index p as

$k = k_1 + N(k_2 - 1), \quad p = p_1 + N(p_2 - 1)$.

All possible values that indexes k and p can take in expressions (1) and (2) can be presented as three non-overlapping sub-sets:

$$\begin{aligned} &k_2 \in [1, L-1] \bigcup k_1 \in [1, N] \Rightarrow p_2 = k_2 \bigcup p_1 \in [1 + k_1, N], \\ &k_2 \in [1, L-1] \bigcup k_1 \in [1, N] \Rightarrow p_2 \in [1 + k_2, L] \bigcup p_1 \in [1, N], \\ &k_2 = L \bigcup k_1 \in [1, N-1] \Rightarrow p_2 = L \bigcup p_1 \in [1 + k_1, N]. \end{aligned}$$

For each of these sub-sets, calculation of the derivatives $\partial m_p / \partial\varphi_j^L$ is a trivial exercise, i.e. $\partial m_p / \partial\varphi_j^L = i m_p \delta_{j,p_2}$,

where the Kronecker symbol $\delta_{j,l} = \begin{cases} 1, j = l, \\ 0, j \neq l. \end{cases}$

Finally, the gradient of the mean-square deviation in the example embodiment can be calculated as

$$\frac{\partial\Delta(\varphi)}{\partial\varphi_j^L}=\frac{\Delta(\varphi)}{\sum\limits_{k=1}^{NL-1}|C_k|^2}\operatorname{Im}\left\{\sum_{k_1=1}^{N}\left[\begin{array}{l} C_{k_1+N(J-1)}\sum\limits_{p_1=k_1+1}^{N}m_{p_1+N(J-1)}m^{*}_{p_1-k_1}+ \\ +C_{k_1+N(L-J)}\sum\limits_{p_1=k_1+1}^{N}m^{*}_{p_1+N(L-1)}m_{p_1-k_1+N(J-1)}+ \\ +\sum\limits_{k_2=1}^{J-1}C^{*}_{k_1+N(k_2-1)}\sum\limits_{p_1=1}^{N}m_{p_1+N(J-1)}m^{*}_{p_1-k_1+N(J-k_2)}+ \\ +\sum\limits_{k_2=1}^{L-J}C^{*}_{k_1+N(k_2-1)}\sum\limits_{p_1=1}^{N}m^{*}_{p_1+N(J-1)}m^{*}_{p_1+k_1+N(J+k_2-2)} \end{array}\right]\right\}.$$

The above analytical expression forms a basis for the gradient method to find L phases φ_j^L, which minimize the mean-square deviation of sampling function $S(z)$. One evaluation of both the mean-square deviation and its gradient requires in the order of N^2L^2 operations, i.e. exactly the same number of operations as in the case of uniform reflection spectrum (prior art). Significant increase of the speed of the algorithm is caused by the decreased dimensionality of the phase space (from LxN for prior art methods to L for the method of the example embodiment).

This has been found to produce considerably optimised sampling functions characterized by low peaks of the refractive index change. Further improvement is achieved by using the second step of the optimisation procedure, in the example embodiment, by a generalization of the iterative Gerchberg-Saxton algorithm or amplitude clipping.

The Gerchberg-Saxton algorithm can be successfully used in cases when a small out-of-band response is not too crucial and the requirements for the spectral resolution are not highly demanding. The key idea of the method is swapping between time/direction and frequency domains under constraints that the amplitude of the complex sampling function is constant whereas the amplitudes of the central part of its spectrum are kept fixed to the desired levels. Iteratively, one translates virtually all modulations of the sampling function $S(z)$ into its phase at the expense of appearance of small side-lobes in the spectrum of the envelope, integral size of which is proportional to the mean-square deviation of $S(z)$.

Iterative clipping procedure is favourable in cases when absence of side-channels in the reflection spectrum is essential. A complex error function is constructed by clipping $S(z)$ at some level S_0. By subtracting the Fourier transform of the error function from the finite spectrum of original S(z), restoring the amplitude profile of the spectrum to the original form

(which includes setting the out-of-band response to zero), one decreases the maximum peak value of $S(z)$. By gradually increasing level S_0, one might significantly reduce the peak of the sampling function.

The advantages of the example embodiment Fourier space encoding approach include: (1) possibility to encode m-level data ($m \geq 2$), i.e. to write structures into a photosensitive medium which lead to the m-level reflection spectrum; (2) increased processing speed, with a potential for real-time optimization of high capacity storage devices (up to 10^9 bits/mkm^2) based on the application of the developed block-coding approach.

The example embodiment is extendable for bit sequences of arbitrary length. One can present a bit sequence of arbitrary length as $N \times L_0 \times L_1 \times L_2 \times ..L_M$. In some cases, extra bits may be required to form the factorisation. In an extension of the example embodiment, one first optimises $N \times L_0$ initial bits using the example embodiment described above. After that the algorithm is repeated with $N \times L_0 \times L_1$ bit sequence, but taking $N \times L_0$ as a "new" N and L_1 as a "new" L_0. Then, one can keep applying the algorithm, until the full bit sequence is optimised.

In Figures 2(a) and (b), a sample two-level coding sequence (in Fourier space) is shown to illustrate the potential of the present invention for storing a series of m-coded elements. Figures 2(c) and (d) show the corresponding amplitude grating design both without clipping (c) and with clipping (d), embodying the present invention and based on the optimisation process described above.

In the following, an example embodiment of an optical data carrier writing system will be described. In Figure 3, an interferometric grating writing apparatus 10, under the control of a system controller 12, is utilised to write a sequence of transverse gratings (one- or multi-dimensional gratings) into a longitudinal strip-like waveguide, in the example embodiment in the form of a photosensitive optical strip 14, which is continuously de-spooled across an interference region 15 of the writing apparatus 10, as indicated by arrow 18.

The writing apparatus 10, under the control of the controller 12, is arranged such that each grating is written transversely into the optical strip 14, which defines a continuous reading face 20 along the optical strip 14, which itself is not twisted during the process. In the example shown in Figure 3, the reading face 20 lies therefore within the x-y plane.

The optical strip 14, after having passed through the interference region 16 is then spooled into a disk-like shape at numeral 22. It is noted that in the disk-shaped configuration at numeral 22, the continuous reading face 20 lies within the x-y plane. That is, the reading face 20 is parallel to the plane of the disk 22.

The spooled disk 22 is then subjected to further processing (indicated at arrow 26) for performing a substantially solid disk 22. In the example embodiment, a refractive index matching optical glue can be used for the formation of the disk 24. In another embodiment, the strip is made of a polymer material which is fully cured only from one side, and only the grating structure is written in that portion, with the top of the initially cured side forming the reading face. After spooling the strip into the disk-shape, the disk is then cured further to achieve a complete solidification. In other embodiments, a possibility to un-roll the disk, e.g. to re-record it, may be provided for. In one such an embodiment, the substantially solid shape may be achieved e.g. by utilising an external plastic ring as a support structure.

Turning now to Figure 4, it is noted that in the disk 24, the reading face 20 lies within the plane of the disk 24. Accordingly, the disk 24 is suitable for data reading e.g. in reflection, similar to the reading conducted in conventionally CD/DVD-type disk readers. It will be appreciated that the aspect of the present invention described with reference to the example embodiment in Figures 3 and 4 above, is not limited to the use with Fourier-based encoding techniques, but can be utilised for any other data recording/storage approaches.

It will be appreciated by the person skilled in the art that numerous modifications and/or variations may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

For example, the partial grating sampling functions and thus the overall sampling function may be one- ore multi-dimensional. Also, the grating structures need not necessarily be UV written. Rather, they may be created by other techniques, including e.g. "stamping" by a master strip or induced by other non-optical means such as e.g. pressure, chemicals, etc.

In some embodiments, to separate the gratings from each other in the spooled or rolled-up state to avoid/reduce cross-talk between channels, some parts of the material strip may be left blank or UV exposed uniformly, i.e. those areas do not have any gratings written/induced.

In the claims that follow and in the summary of the invention, except where the context requires otherwise due to express language or necessary implication the word "comprising" is used in the sense of "including", i.e. the features specified may be associated with further features in various embodiments of the invention.

Claims

1. An optical data carrier having a data reading face and comprising a plurality of grating structures in each of which a series of m-level coded elements, $m \geq 2$, is stored, the grating structures being optically accessible from the reading face for reading of the series of coded elements.

2. An optical data carrier as claimed in claim 1, wherein a maximum in the refractive index variation defining the grating structures in the optical data carrier is less than directly proportional to the number of coded data elements in each grating structure.

3. An optical data carrier as claimed in claims 1 or 2, wherein the optical data carrier is disk-shaped.

4. An optical data carrier as claimed in any one of the preceding claims, wherein the grating structures comprise one- or multi-dimensional grating structures.

5. An optical data carrier as claimed in any one of the preceding claims, wherein the optical data carrier comprises a rolled-up material strip in which the plurality of grating structures are formed.

6. An optical data carrier as claimed in claim 5, further comprising means for maintaining the material strip in a rolled-up state.

7. An optical data carrier as claimed in claim 6, wherein the means for maintaining comprises a curable material.

8. An optical data carrier as claimed in claim 6, wherein the means for maintaining comprises a mechanical structure.

9. A method of holographic storing of a series of m-level coded elements in an optical data carrier, $m \geq 2$, the method comprising the step of:

a) forming the sampling function as a direct sum of N partial grating sampling functions, each partial grating sampling function having phases and amplitudes, represented by φ_n, d_n, respectively;

wherein each d_n has m possible values.

10. A method as claimed in claim 5, wherein the method further comprises:

b) conducting an optimisation process to determine a set of phases φ_n for which a required maximum refractive index variation in the optical data carrier is less than directly proportional to the number of coded data elements in the series.

11. A method as claimed in claim 6, wherein step a) comprises:

a1) forming the sampling function as a direct sum of L groups of N partial grating sampling functions, each LxN partial grating sampling functions having phases and amplitudes, represented by matrices φ_{nl}, d_{nl}, respectively;

and step b) comprises:

b1) separating the matrix φ_{nl} into sets of N phases for each group of N partial grating sampling functions in a given group, and one set of L phases between the L groups;

b2) determining the sets of phases for each group of N partial grating sampling functions from a database having stored therein possible combinations of N coded data elements and associated sets of phases; and

b3) conducting an optimisation process to determine the set of L phases between the L groups for which a required maximum refractive index variation in the optical data carrier is less than directly proportional to the number of coded data elements in the series.

12. A method as claimed in claim 11, wherein step b3) comprises conducting the optimisation process to determine the set of L phases between the L groups for which a functional of the sampling function is minimised.

13. A method as claimed in claim 12, wherein the functional comprises a mean-square deviation or maximum amplitude.

14. A method as claimed in claims 12 or 13, wherein step b3) comprises applying a functional analysis to determine the set of L phases between the L groups for which the functional of the sampling function is minimised.

15. A method as claimed in claim 14, wherein the functional analysis comprises a steepest descent (gradient) method.

16. A method as claimed in claims 14 or 15, wherein step b3) comprises approximating the functional of the sampling function utilising an aperiodic autocorrelation function.

17. A method as claimed in claim 16, wherein step b3) further comprises deriving a gradient of the functional of the sampling function from a derivative of the aperiodic autocorrelation function.

18. A method as claimed in any one of claims 9 to 17, wherein the partial grating sampling functions comprise one- or multi-dimensional functions.

19. A method of storing data in an optical data carrier, the method comprising the steps of:

- storing the data into a material strip, and

- arranging the material strip to form the optical data carrier and in a manner such that the data is optically accessible from a reading face of the optical data carrier for reading the stored data.

20. A method as claimed in claim 19, wherein arranging the material strip comprises spooling the material strip into a disk-shaped optical data carrier.

21. A method as claimed in claims 19 or 20, wherein the material strip comprises a photosensitive material strip, and the step of storing the data comprises photo-inducing refractive index changes in the photosensitive material strip to form grating structures for holographic storing the data.

22. An optical data carrier comprising a material strip arranged in a manner such that data stored in the material strip is optically accessible from a reading face of the optical data carrier for reading the data.

23. An optical data carrier as claimed in claim 22, wherein the optical data carrier is disk-shaped and comprises the material strip spooled into a disk shape.

24. An optical data carrier as claimed in claims 22 or 23, wherein the material strip comprises a plurality of grating structures containing the optical data, and wherein each grating structure is optically accessible from the reading face.

25. An optical data carrier as claimed in any one of claims 22 to 24, further comprising means for releasably maintaining the material strip in the disk shape.

Dated this 23rd day of July 2003

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by its attorneys

Freehills Carter Smith Beadle

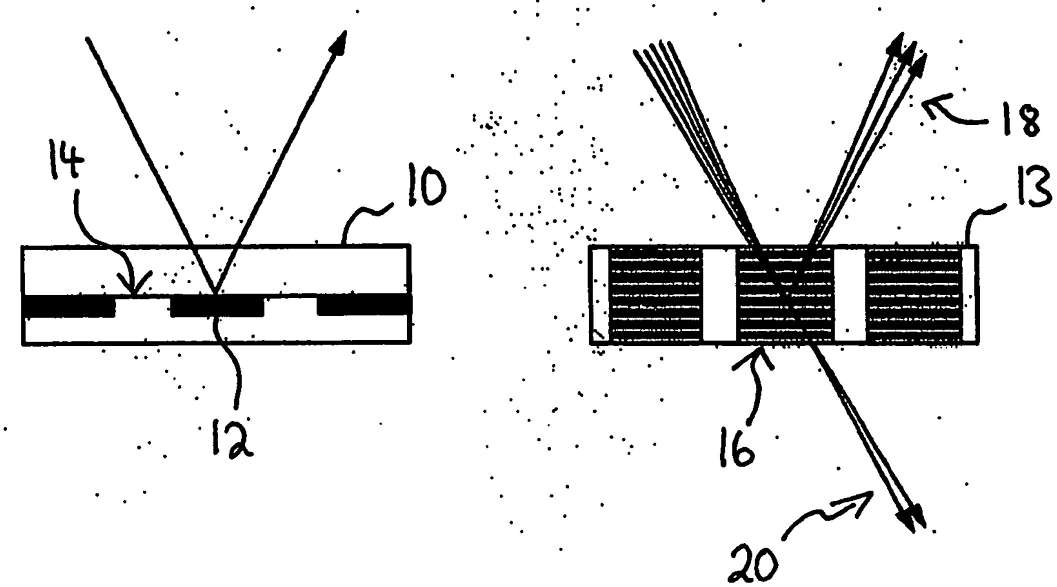

Fig. 1

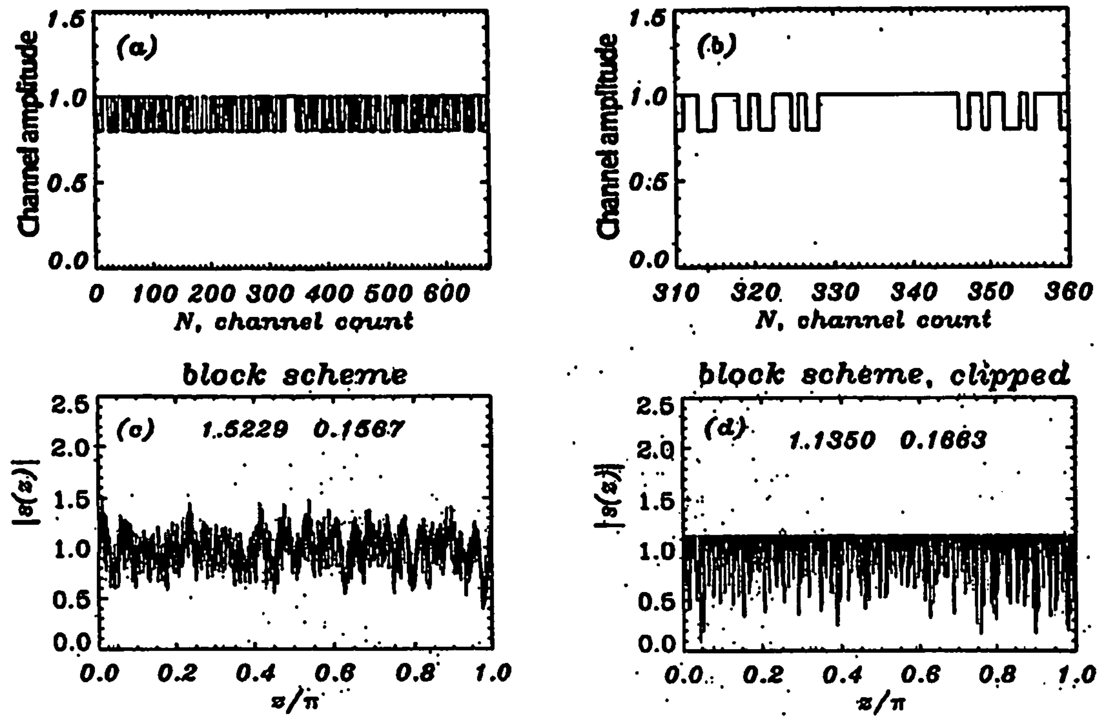
(a)
Channel amplitude
N, channel count
(b)
Channel amplitude
N, channel count
block scheme
(c) 1.5229 0.1567
|s(x)|
x/π
block scheme, clipped
(d) 1.1350 0.1663
|s(x)|
x/π

Fig. 2

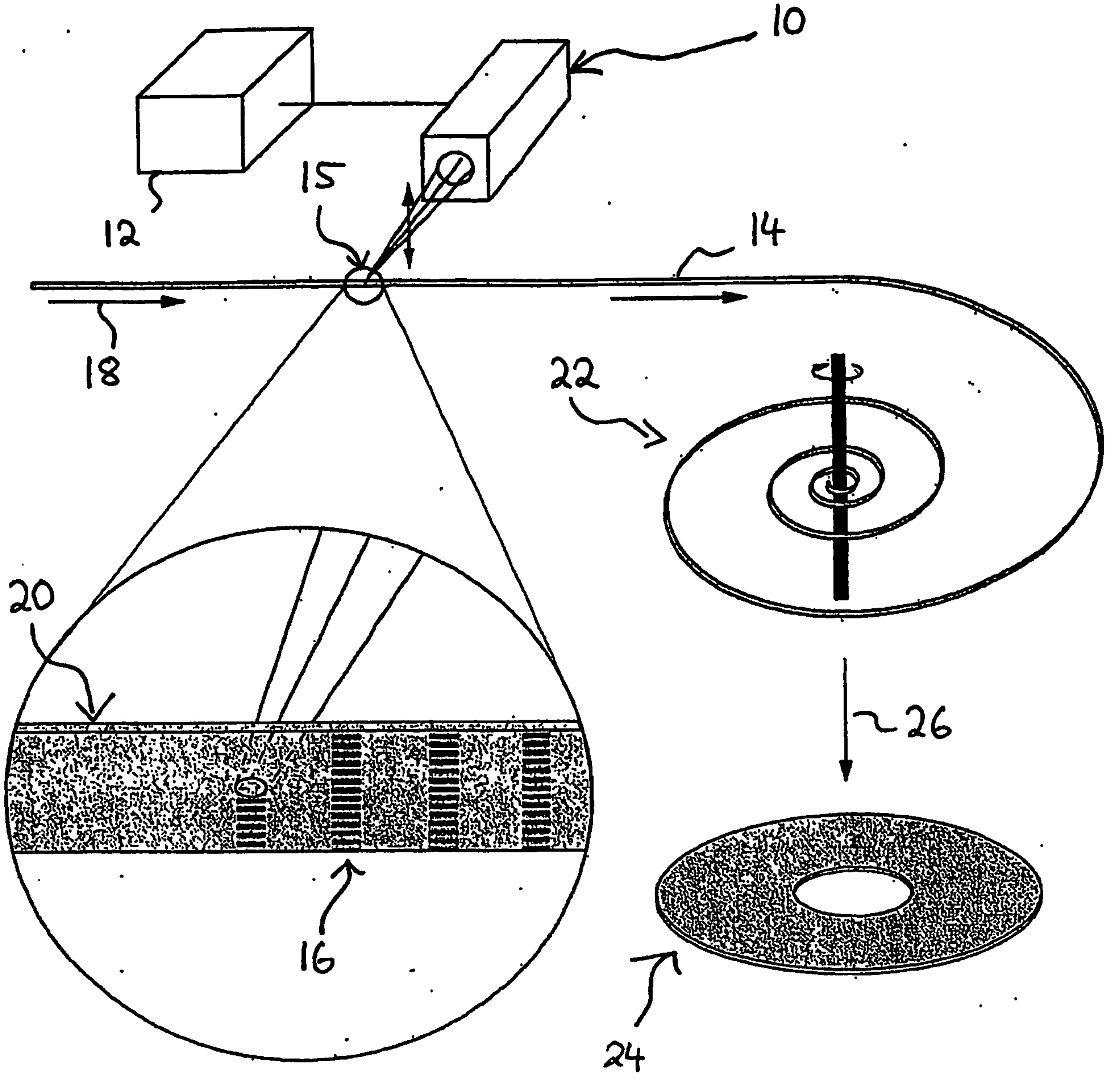

Fig. 3

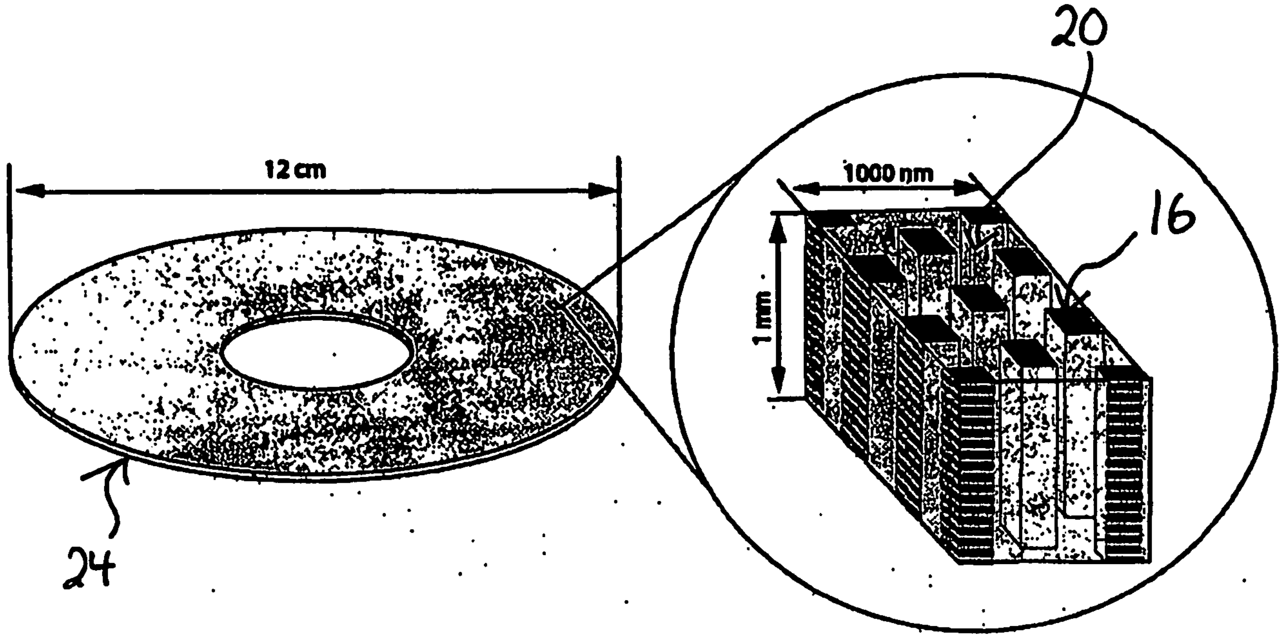

Fig. 4